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(54) Engine ignition system using laser beam

(57) A system for igniting the mixture in the combustion chambers of an internal combustion engine uses a laser beam radiated towards each combustion chamber from a respective semiconductor laser unit (301 to 304). The radiated lasser beam is condensed at a point within the combustion chamber. A laser drive circuit (20) is provided which comprises a capacitor (212), a DC–DC converter (210) for applying a high voltage across the capacitor (212), and transistor switching circuits (221 to 224) for permitting the supply of the high energy accumulated in the capacitor (212) to the semiconductor laser unit (301 to 304) in accordance with ignition timing control signals from a circuit (10).

FIG.3

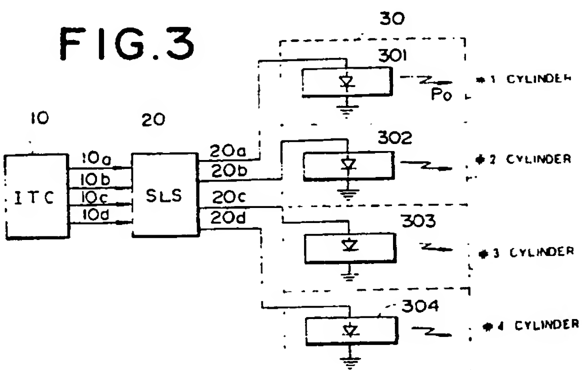

FIG.6

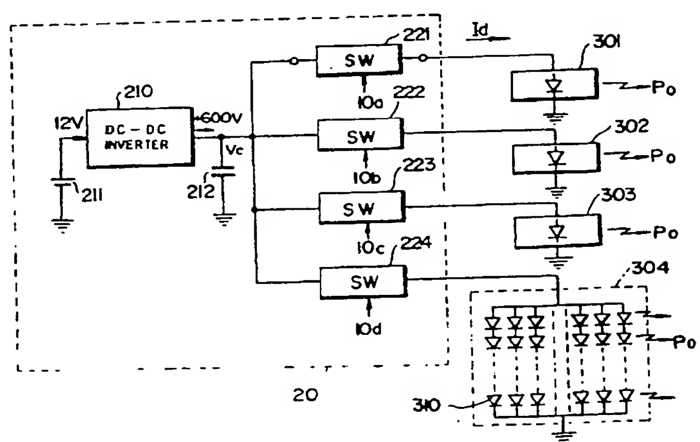

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FIG.1
(PRIOR ART)

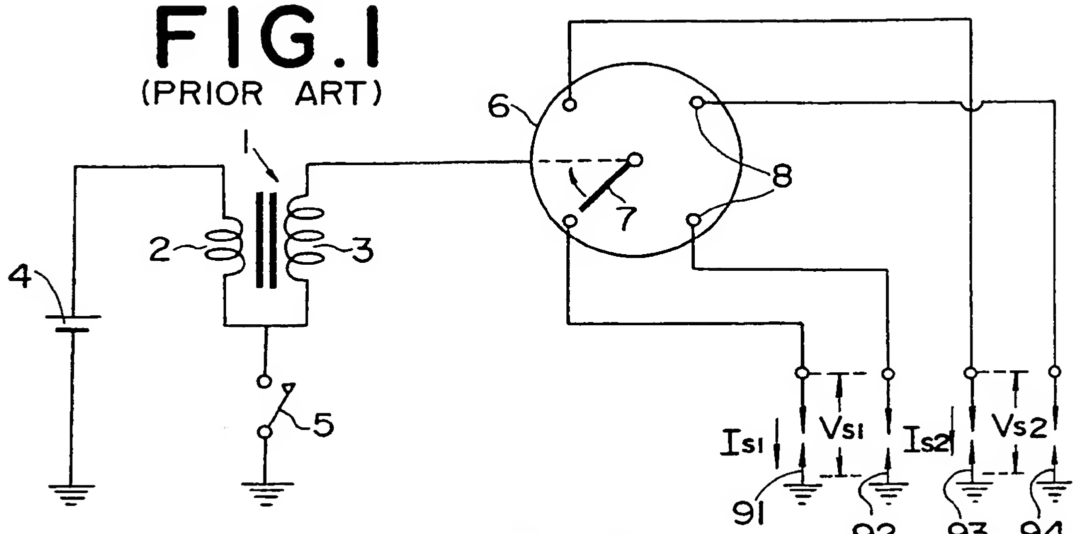


FIG.2 (PRIOR ART)

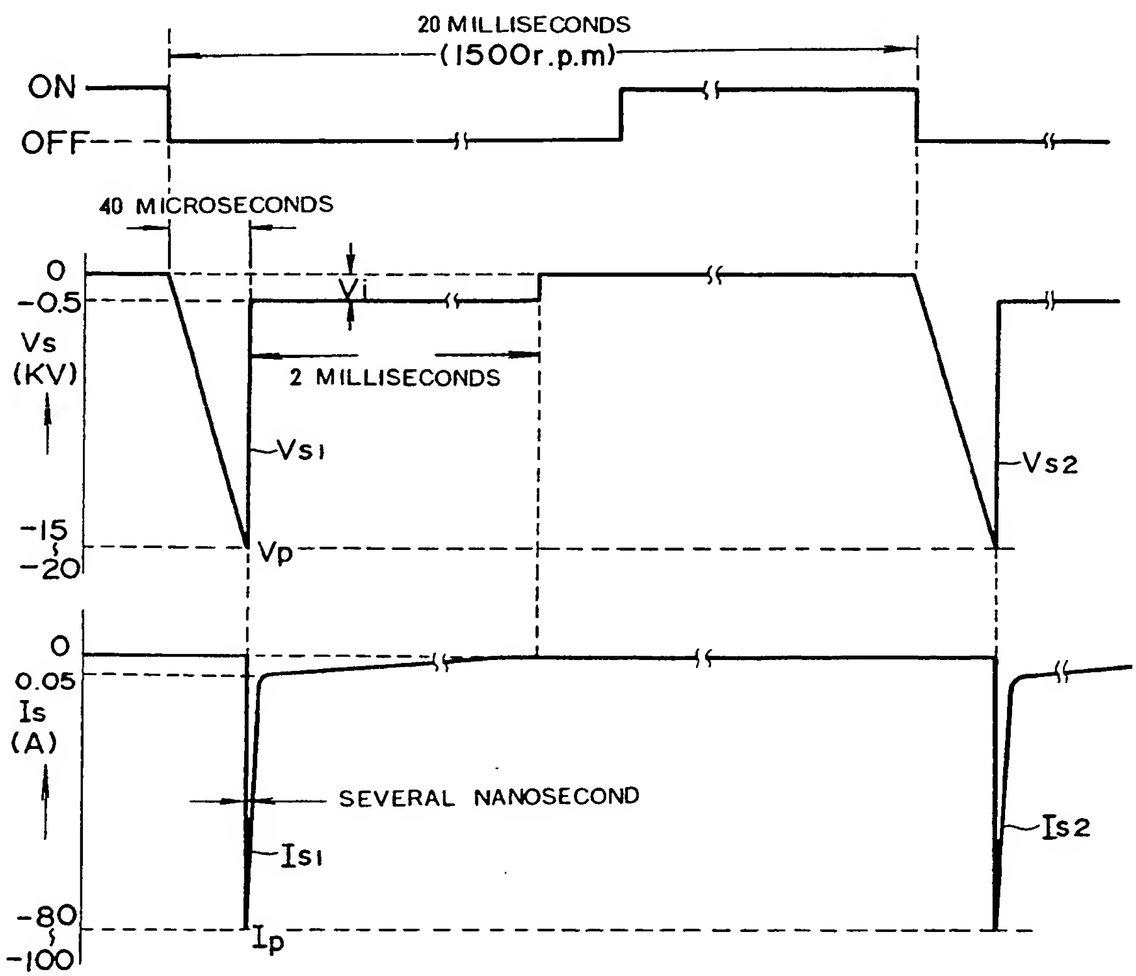


FIG.3

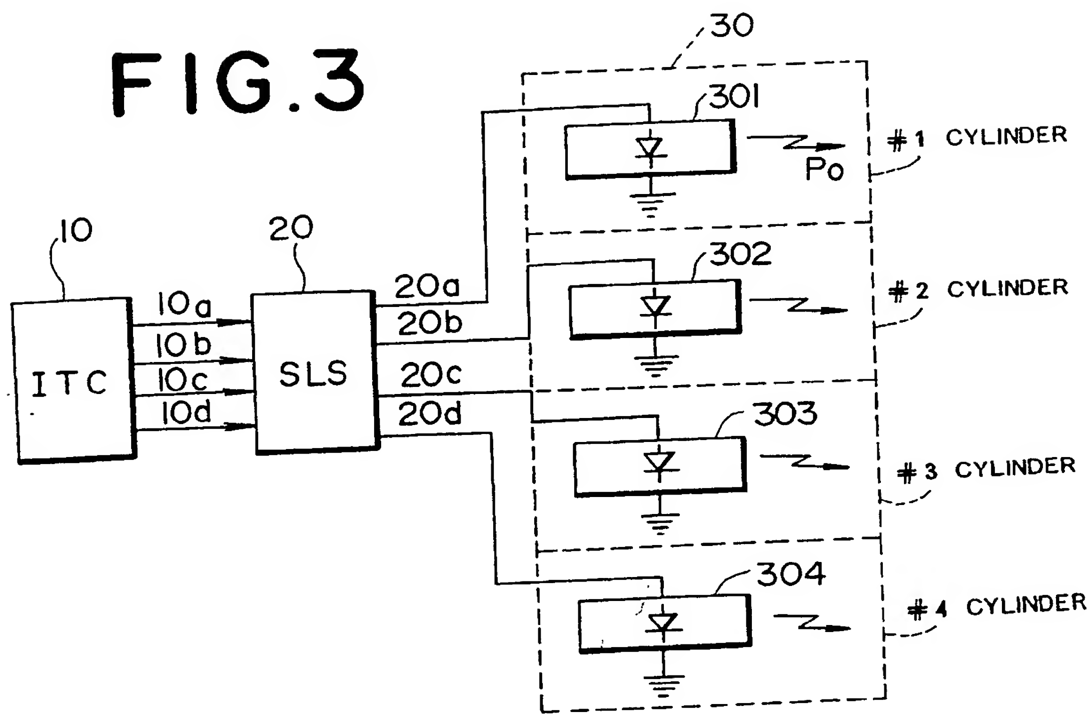

30
301
302
303
304
Po
#1 CYLINDER
#2 CYLINDER
#3 CYLINDER
#4 CYLINDER
10
20
ITC
SLS
10a
10b
10c
10d
20a
20b
20c
20d

FIG.4

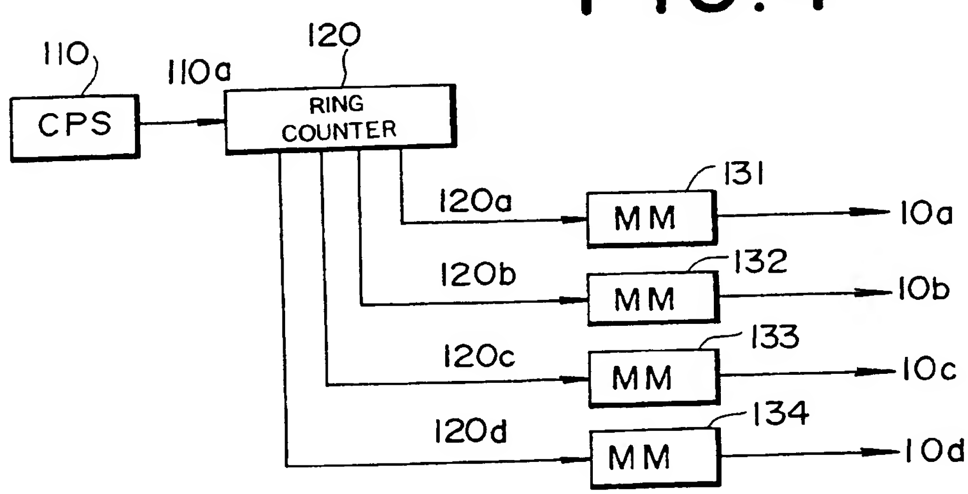

110
CPS
110a
120
RING COUNTER
120a
120b
120c
120d
MM
MM
MM
MM
131
132
133
134
10a
10b
10c
10d

FIG.5

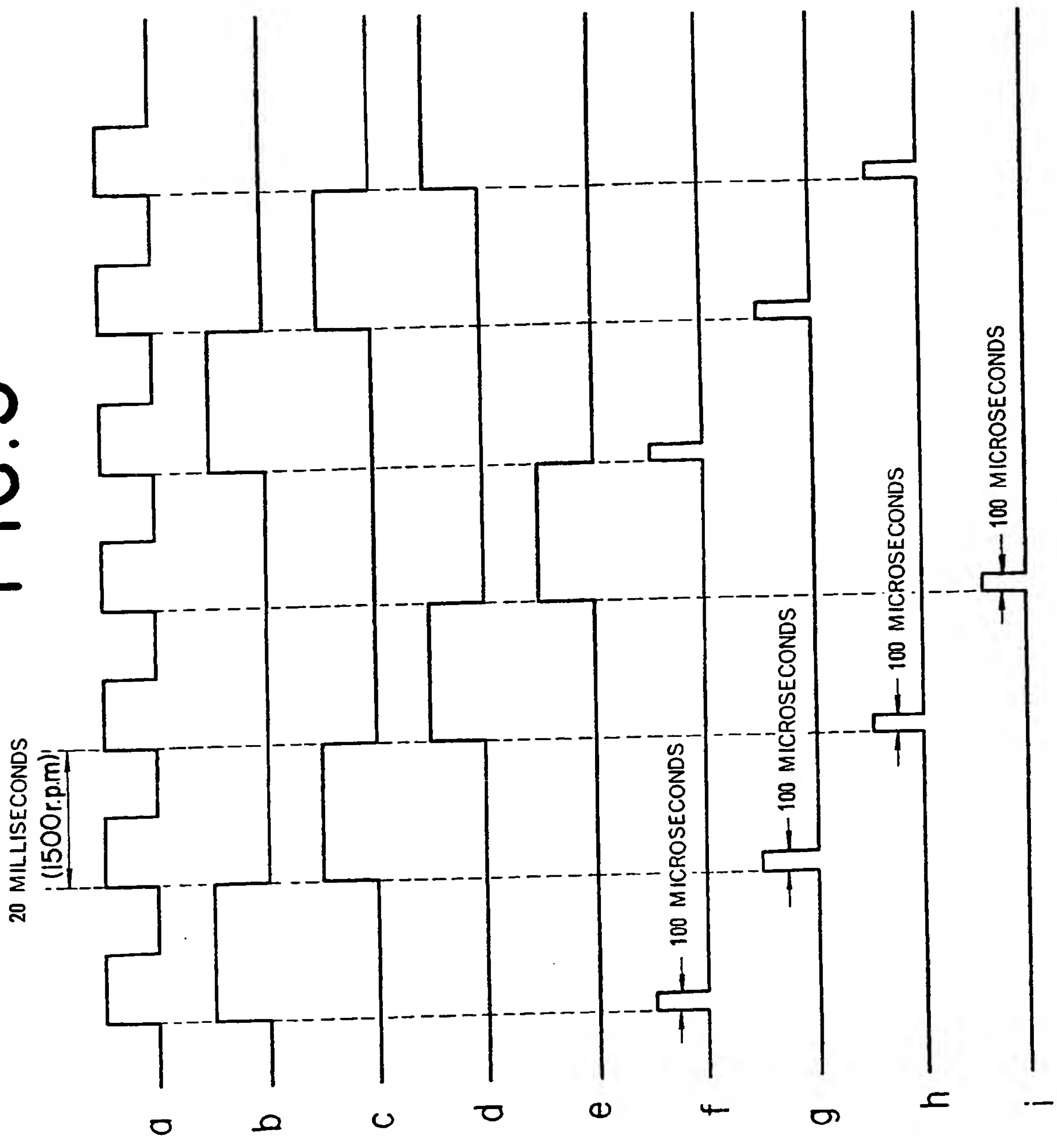
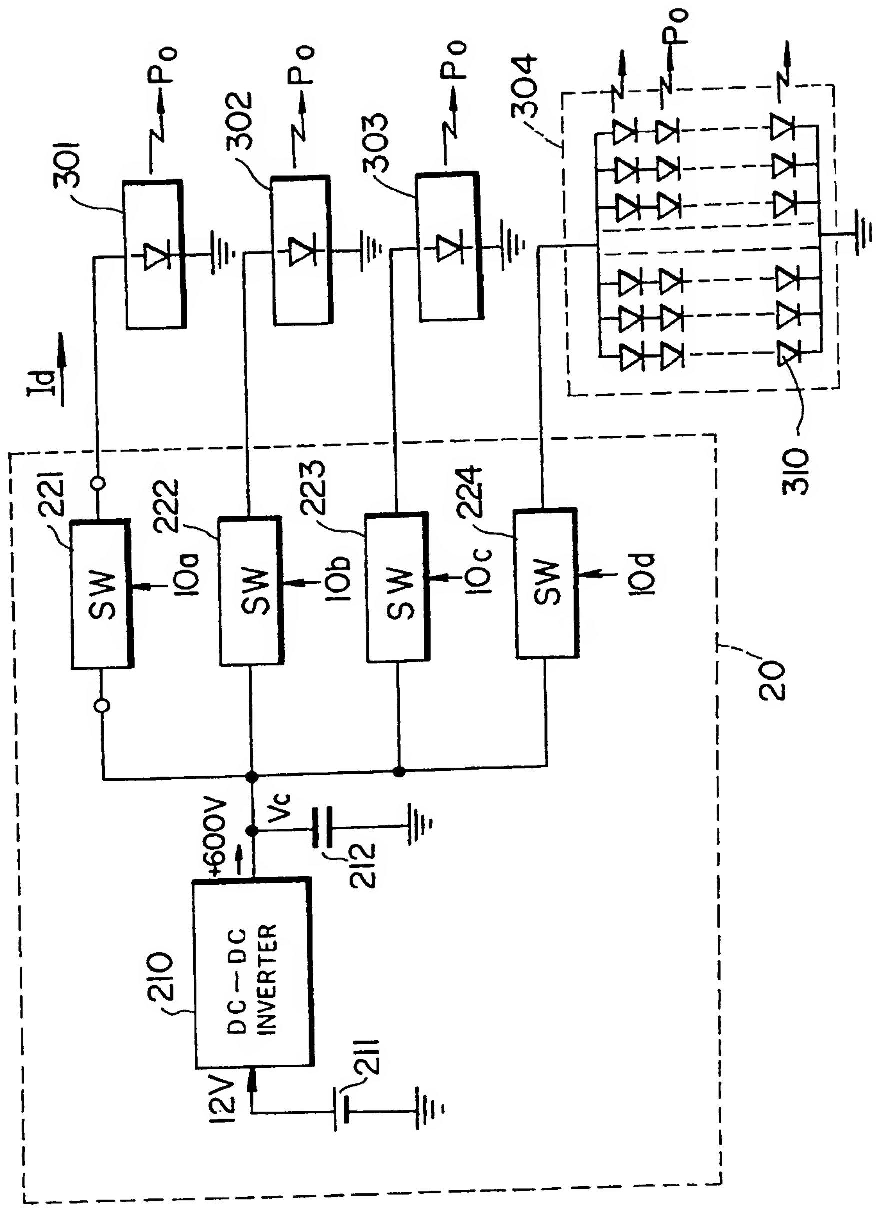

20 MILLISECONDS
(1500r.p.m.)
100 MICROSECONDS
100 MICROSECONDS
100 MICROSECONDS
100 MICROSECONDS
a
b
c
d
e
f
g
h
i

FIG.6


301
302
303
304
Po
Po
Po
Po
Id
221
222
223
224
SW
SW
SW
SW
10a
10b
10c
10d
310
20
+600V
Vc
212
210
DC—DC INVERTER
12V
211

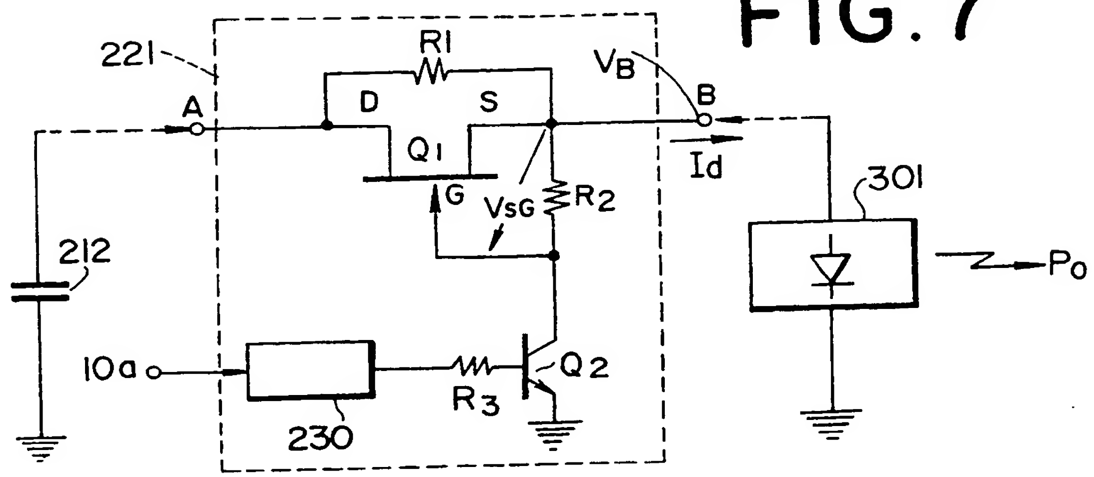

221
A
R1
D
S
Q1
G
VSG
R2
VB
B
Id
301
Po
212
10a
230
R3
Q2

FIG. 7

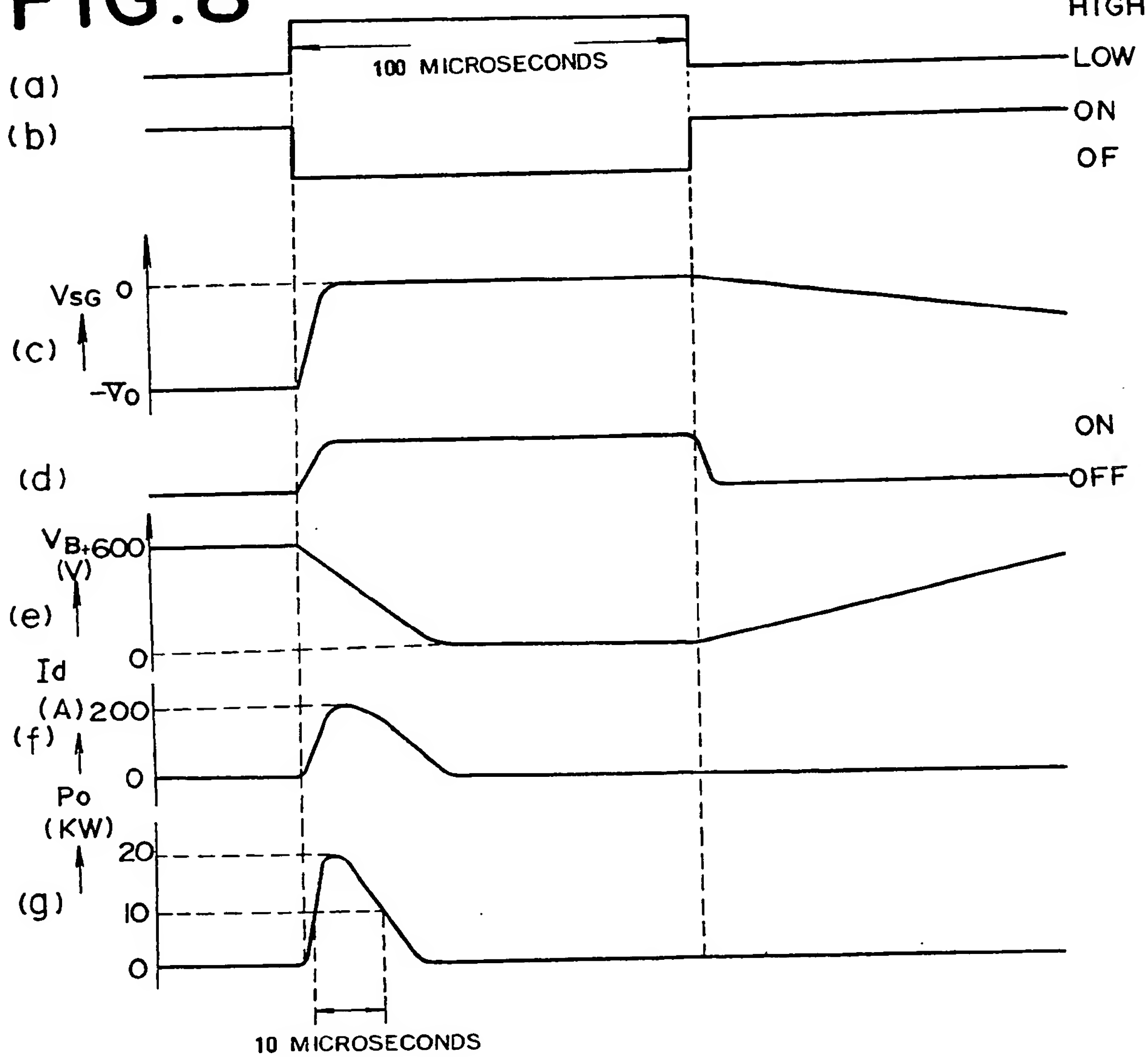

100 MICROSECONDS
(a)
(b)
HIGH
LOW
ON
OF
(c)
VSG
0
-V0
(d)
ON
OFF
(e)
VB +600 (V)
0
(f)
Id (A)
200
0
(g)
Po (KW)
20
10
0
10 MICROSECONDS

FIG. 8

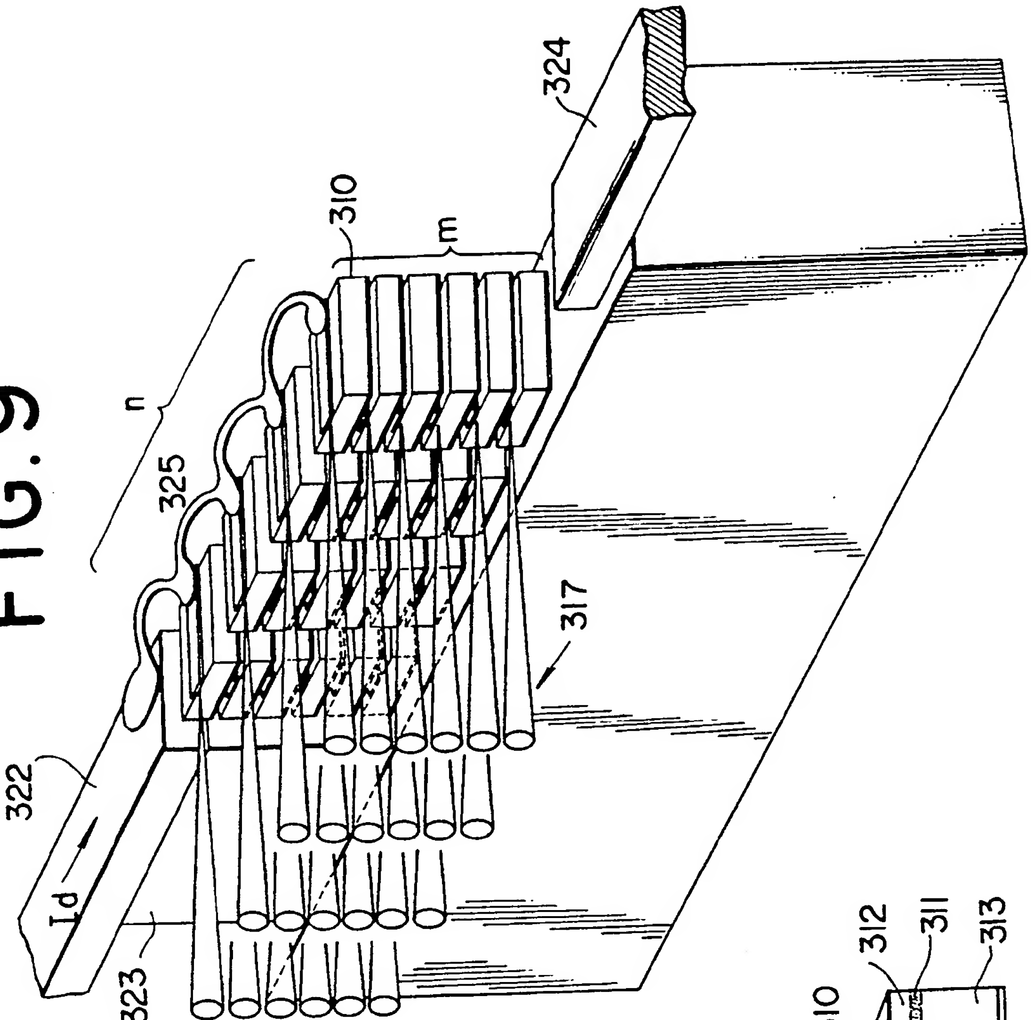


FIG.9

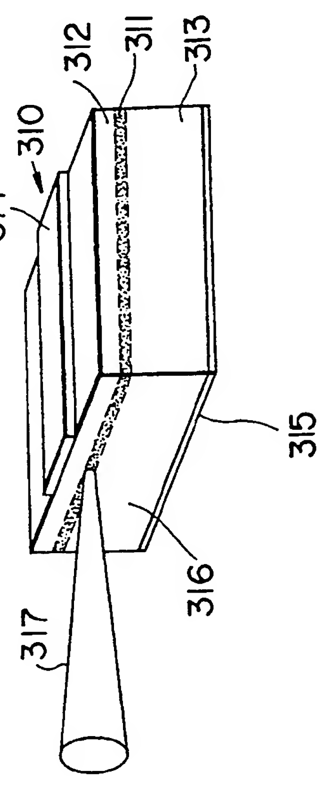
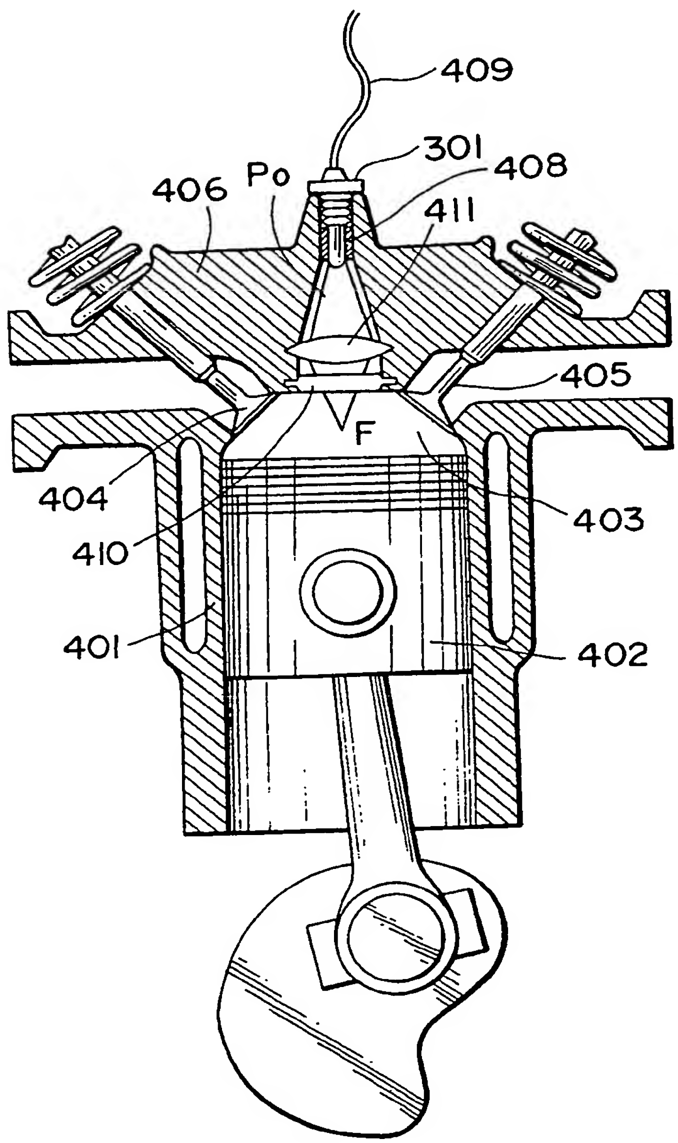


FIG.10

FIG. 11



SPECIFICATION

Engine ignition syst m using laser b am

BACKGROUND OF THE INVENTION

1. *Field of the Invention*

This invention relates to an ignition system for use in an internal combustion engine and, more particularly, to such a system for igniting mixture using laser beams radiated from semiconductor laser units.

2. *Description of the Prior Art*

In order to ignite the mixture charged in engine combustion chambers, spark ignition systems have normally been employed which develop high voltage pulses periodically and distribute them sequentially to the associated spark plugs to discharge sparks thereat. It has been found, however, that during such spark discharge, impulse current flows through the ignition system, causing undesirable noise field production.

The present invention provides an uncomplicated ignition system for igniting mixture using laser beams radiated from semiconductor laser units instead of spark discharge.

SUMMARY OF THE INVENTION

There is provided, in accordance with the present invention, an ignition system for use in an internal combustion engine having at least one combustion chamber. The ignition system comprises an ignition timing control circuit for determining the engine ignition timing based upon various engine operating parameters and providing an ignition timing control signal indicative of the determined ignition timing. The ignition timing control signal is applied to a laser drive circuit which thereby provide a laser drive signal in timed relation with the determined ignition timing. A semiconductor laser unit is provided which radiates a giant laser beam towards the combustion chamber in response to the laser drive signal from the laser drive circuit. The radiated laser beam is condensed at a point within the combustion chamber. The ignition system utilizes optical energy instead of electric energy to ignite mixture and thus is free from noise field production.

The laser drive circuit comprises a capacitor, a voltage source for applying a high voltage across capacitor, and switching means for connecting the capacitor to the semiconductor laser unit in response to the ignition timing control signal from the ignition timing control circuit. The laser beams are obtained by applying high energy stored in the capacitor and modulated in pulse form to the semiconductor laser unit. Thus, the ignition system requires a smaller power source. The semiconductor laser unit comprises a plurality of columns of diode laser chips connected in series with each other, the diode laser chip columns being connected in parallel with each other.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be described in greater detail by reference to the following description taken in connection with the accompanying drawings, in which:

Figure 1 is a schematic diagram showing a conventional spark ignition system;

Figure 2 is a graph showing the waveforms of the voltage and current attendant upon spark discharge in the conventional spark ignition system of Fig. 1;

Figure 3 is a block diagram showing one embodiment of an ignition system made in accordance with the present invention;

Figure 4 is a block diagram showing the ignition timing control circuit used in the ignition system of Fig. 3;

Figure 5 contains nine waveforms a to i obtained at various points in the ignition timing control circuit of Fig. 4;

Figure 6 is a block diagram showing the laser drive circuit used in the ignition system of Fig. 3;

Figure 7 is a diagram showing one example of the switching circuit used in the laser drive circuit of Fig. 6;

Figure 8 contains seven waveforms a to g obtained at various points illustrated in Fig. 7;

Figure 9 is a perspective view showing the semiconductor laser unit used in the ignition system of Fig. 3;

Figure 10 is a perspective view showing one diode laser chip contained in the semiconductor laser unit of Fig. 9; and

Figure 11 is a sectional view showing the position of the semiconductor laser unit with respect to an engine combustion chamber.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Prior to the description of the preferred embodiment of the present invention, a prior art spark ignition system will be described in order to specifically point out the difficulties attendant thereon.

Referring to Fig. 1, the conventional spark ignition system for use in automotive vehicle engines is illustrated which includes an ignition coil 1 having its primary winding 2 connected to the vehicle battery 4. The primary winding 2 of the ignition coil 1 is also connected to ground through switching means 5 adapted to turn on and off in synchronism with engine rotation to cause spark firing energy to be developed to fire the spark plugs of the engine. The secondary winding 3 of the ignition coil 1 is connected to the rotor contact 7 of a distributor 6 which rotates in synchronism with the operation of the switching means 5 to sequentially connect contacts 8 to the respective spark plugs 91 to 94.

When switched off, the switching means 5 shuts off the current flow through the primary

winding 2 of the ignition coil 1, causing a high voltage pulse across the second winding 3. Normally, the high voltage pulse has a peak value ranging between − 20 kilovolts and − 25 kolovolts. The high voltage pulses Vs are applied through the distributor 6 sequentially to the spark plugs 91 to 94.

As shown in Fig. 2, wherein Vs1 and Vs2 represent the high voltage pulses applied to the spark plugs 91 and 92 and Is1 and Is1 represent the impulse current during spark discharge at the spark plugs 91 and 92, the high voltage pulses have a peak value Vp ranging between − 15 kilovolts and − 20 kilovolts. When the high voltage pulse Vs reaches its peak value Vp, a mixture dielectric breakdown occurs at the spark plug so that the charge accumulated between the distributor contact and the spark plug discharges. This capacitative discharge is followed by about − 0.5 kilovolts and about 2 millisecond inductive discharge caused by the inductive energy from the ignition coil 1. The sparks attendant on the capacitive and inductive discharges assure the mixture ignition and combustion.

Since such a conventional spark ignition system periodically develops high voltage pulses having a peak value of about − 20 kilovolts in order to obtain sufficient spark firing energy, discharges occur between the distributor rotor and side contacts. During capacitive discharge, the charge accumulated near the electrodes is discharged in an instant to cause impulse current having a several-ten ampere peak value and a several-nanosecond pulse width. Additionally, impulse current Is flows through the spark plug during capacitive discharge which has a peak value Ip ranging between − 80 amperes and − 100 amperes and a pulse width of several nanoseconds, as shown in Fig. 2. Such impulse current has a wide frequency band ranging between several-ten megahertz to several-hundred megahertz and causes noise field radiated from the ignition circuit connected to the spark plugs and the distributor to produce noise problems over a wide frequency range.

Referring now to Fig. 3, there is illustrated in diagram form one embodiment of an engine ignition system made in accordance with the present invention. In Fig. 3, the reference numeral 10 generally designates an ignition timing control circuit (ITC) which determines a desired ignition timing value based upon various engine operating parameters and provides ignition timing control signals 10a, 10b, 10c and 10d. The ignition timing control signals are fed to a semiconductor laser drive circuit (SLS) 20 which thereby provides high-energy drive signals 20a, 20b, 20c and 20d to a giant laser beam generator 30. The giant laser beam generator 30 is shown as containing four diode laser units 301 to 304 for respective engine cylinders. Each diode laser unit produces a giant pulse laser beam which is focussed through a condenser to a proper point within the associated combustion chamber for mixture ignition and combustion. The giant pulse laser beam has a peak value of about 20 kilowatts and a pulse width of 10 microseconds.

Referring to Figs. 4 and 5, the ignition timing control circuit 10 will be described in greater detail. The circuit 10 comprises an optical or electromagnetic crankshaft position sensor (CPS) 110 adapted to produce, in synchronism with engine rotation, a train of electrical pulses 110a the falling edges of which occur in coincidence with the determined engine ignition timing. In this embodiment, the crankshaft position sensor 110 provides a pulse signal 110a having two pulses for every engine rotation and thus a pulse period of 20 milliseconds when the engine rotates at 1,500 rpm, as shown in Fig. 5a. The pulse signal 110a is applied to a ring counter 120 which thereby produces four pulse signals 120a, 120b, 120c and 120d going high sequentially in synchronism with the occurrence of the leading edges of the pulse signal 110a, as shown in Figs. 5b to 5e, respectively. The pulse signals 120a, 120b, 120c and 120d are applied to respective monostable multivibrators 131, 132, 133 and 134 which are selected to have a 100 microsecond metastable equilibrium time. At the outputs of the respective monostable multivibrators there appear ignition timing control signals 10a, 10b, 10c and 10d having a 100 microsecond pulse width, as shown in Figs. 5f to 5i, respectively.

Referring to Figs. 6 to 8, the semiconductor laser drive circuit 20 will be described in more detail. In Fig. 6, the reference numeral 210 indicates a DC–DC inverter connected at its input to the positive side of the 12-volt vehicle battery and connected at its output to ground through a 5 μF capacitor 212 with high dielectric strength. The DC–DC inverter 210 produces at its output a 600-volt DC voltage which is applied across the capacitor 212. The capacitor 212 accumulates a high energy of about 1 joule which is supplied sequentially to the diode laser units 301 to 304 through respective switching circuits 221 to 224 switched on and off by the pulse signals 20a to 20d, respectively.

Each diode laser unit has a stack structure, as will be described in detail, wherein n series connections of m diode laser chips 310 are connected in parallel with each other. When supplied with the high energy from the capacitor 212, the diode laser unit produces a giant pulse laser beam Po having a 20 kilowatt peak value as a result of each diode laser chip 310 producing a several-watt laser beam. Although Fig. 6 illustrates such a stack structure for the diode laser unit 304 only, it is to be noted that the other diode laser units 301

to 303 are substantially similar in structure to the diode laser unit 304.

As shown in Fig. 7, the switching circuit 221 comprises a field-effect transistor (FET) Q1 having a drain electrode D connected through an input terminal A to the capacitor 212 together with a source electrode S connected through an output terminal B to the diode laser unit 301. The gate electrode G of the field-effective transistor Q1 is connected to ground through the collector-emitter path of a switching transistor Q2. A first resistor R1 is connected between the drain and source electrodes of the field-effect transistor Q1 and a second resistor R2 is connected between the source and gate electrodes thereof. The switching circuit 221 also comprises an inverter 230 having its input coupled to the ignition timing control signal 10a from the ignition timing control circuit 10. The inverted output from the inverter 230 is applied through a resistor R3 to the base of the switching transistor Q2 which thereby is switched on and off.

The resistor R1 is selected to have a proper value high enough to hold small the leak current from the capacitor 212 as compared to the charge current from the DC–DC inverter 210. The values of the resistors R1 and R2 are suitably selected to meet the requirement that, when the switching transistor Q2 is turned on, the voltage V_{SG} between the gate and the source electrodes of the field-effect transistor Q1 is held at a voltage $-Vo$ lower than the pinch-off voltage Vp as follows:

$$-Vo = -\frac{R2}{R1 + R2} \times 600\ (\text{volt}) < Vp$$

When the ignition timing control signal 10a is at its low level, as shown in Fig. 8a, the switching transistor Q2 is held on, as shown in Fig. 8b. The voltage V_{SG} is $-Vo$, as shown in Fig. 8c, and the field-effect transistor Q1 is held nonconductive, as shown in Fig. 8d. As a result, there is no giant pulse laser beam Po, as shown in Fig. 8g.

When the ignition timing control signal 10a goes high, as shown in Fig. 8a, the switching transistor Q2 is switched off, as shown in Fig. 8b, to disconnect the gate electrode of the field-effect transistor Q1 from ground. This changes the voltage V_{SG} to zero, as shown in Fig. 8c, causing the field-effect transistor Q1 to become conductive, as shown in Fig. 8d. As a result, the high energy accumulated in the capacitor 212 is supplied through the field-effect transistor Q1 to the diode laser unit 301 which thereby produces a giant pulse laser beam Po with a peak value of 20 kilowatts and a pulse width of 10 microseconds, as shown in Fig. 8g. Figs. 8e and 8f illustrate variations in the voltage V_B at the output terminal B and the current Id through the output terminal B.

Referring to Fig. 9, the diode laser unit 304 comprises a copper heat sink 321 on which n columns of m diode laser chips are placed. As shown in Fig. 10, each diode laser chip 310 comprises a GaAs crystal having a size of 100 × 100 × 300 microns. The GaAs crystal has an AlGaAs double-hetero structure wherein an about 0.3 micron thickness GaAs active layer 311 is sandwiched between two AlGaAs crystal layers 312 and 313 different in refractive index. A 20 micron width positive electrode strip plate 314 is attached on the upper surface of the GaAs crystal and a negative electrode plate 315 is formed on the lower surface thereof. A laser beam 317 is radiated from the side surface of the diode laser chip at a point of the GaAs active layer 311 below the positive electrode plate 314.

A positive electrode lead 322 for connection to the output terminal B of the switching circuit is fixed to a high heat-conductive electric insulator 323 attached on the heat sink 321 on one side of the diode laser stack structure. The insulator 323 may be made of beryllia porcelain. A negative electrode lead 324 is attached directly to the heat sink 321 on the other side of the diode laser stack structure. A gold wire 325 is used to electrically connect the positive electrode plates 314 of the uppermost diode laser chips of the respective stacked columns to the positive electrode lead 322. Thus, n series circuits of m diode laser chips are connected in parallel with each other. When an about 600-volt voltage pulse is applied between the positive and negative electrode leads 322 and a current Id having a 200-ampere peak value flows, the diode laser chips 310 radiate laser beams 317 from the side surfaces thereof.

Referring to Fig. 11, the engine includes four water-cooled cylinders, one of which is illustrated by the reference numeral 401. A cylinder head 406 closes the upper end of the cylinder 401 to form therewith a combustion chamber 403 within which a piston 402 is adapted to reciprocate. The cylinder head 406 is provided with passages opening into the combustion chamber 403 through a pair of ports, the flow therethrough being controlled by two poppet type valves 404 and 405. The cylinder head 406 is also provided with a bore 407 extending therethrough and opening centrally into the combustion chamber 403. The diode laser unit 391 is fitted in the upper portion of the bore 407 through a copper spacer 408. A cable 409 extends from the diode laser unit 301 for connection to the laser drive circuit 20. A silica glass window 410 is mounted to the cylinder head 406 to separate the bore 407 from the combustion chamber 403. Provided between the diode laser unit 301 and the window 410 is a condenser lens 411 for focussing the laser beam radiated from the diode laser unit 301

at a proper point F within the combustion chamber 403.

When the high-energy drive pulse signal 20a is applied through the cable 409 to the diode laser unit 301, it radiates a giant laser beam Po which is condensed through the convex lens 411 at the focus F within the combustion chamber 403. The energy of the laser beam concentrated at the focus F is about 100 millijoules which causes ionization and dielectric breakdown of the compressed mixture within the combustion chamber 403. The produced high temperature, high pressure, plasma gas ignits and burns the mixture.

The present invention procides an uncomplicated ignition system for igniting mixture using giant laser beams radiated from semiconductor laser units instead of spark discharge. The ignition system can eliminate the occurrence of undesirable noise field resulting from impulse current attendant on spark discharge found in spark ignition system. The giant laser beams are obtained by applying high energy accumulated in a capacitor and modulated in pulse form to the semiconductor laser units. Thus, the ignition system requires a smaller power source for producing giant laser beams as compared to systems using gas or solid lasers such as CO_2 lasers, ruby lasers, YAG lasers, etc.

While the present invention has been described in conjunction with a specific embodiment thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims.

CLAIMS

1. An ignition system for use in an internal combustion engine having at least one combustion chamber comprising:

(a) an ignition timing control circuit for determining the engine ignition timing based upon various engine operating parameters and providing an ignition timing control indicative of the determined ignition timing;

(b) a laser drive circuit responsive to the ignition timing control signal from said ignition timing control circuit for providing a laser drive signal in timed relation with the determined ignition timing;

(c) a semiconductor laser unit responsive to the laser drive signal from said laser drive circuit for radiating a giant laser beam toward said combustion chamber; and

(d) means for condensing the giant laser beam from said semiconductor laser unit at a point within said combustion chamber.

2. An ignition system according to claim 1, wherein said laser drive circuit comprises a capacitor, a source of voltage for applying a high voltage across said capacitor, and switching means for connecting said capacitor to said semiconductor laser unit in response to the ignition timing control signal from said ignition timing control circuit.

3. An ignition system according to claim 2, wherein said source of voltage comprises a battery and a DC–DC inverter connected between said battery and said capacitor.

4. An ignition system according to claim 2, wherein said switching means comprises a switching transistor having its base coupled to the ignition timing control signal from said ignition timing control circuit, and a field-effect transistor having a drain electrode connected to said capacitor and a source electrode connected to said semiconductor laser unit, and a gate electrode connected to ground through the collector-emitter path of said field-effect transistor.

5. An ignition system according to claim 1, wherein said semiconductor laser unit comprises a plurality of columns of diode laser chips connected in series with each other, said diode laser chip columns being connected in parallel with each other.

6. An ignition system according to claim 5, wherein each of said diode laser chips comprises a GaAs active layer sandwiched between to AlGaAs layers different in refractive index.

7. An ignition system for use in an internal combustion engine substantially as hereinbefore described with reference to Figs. 3 to 11 of the accompanying drawings.

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